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Updated life history parameters for northern Gulf of St. Lawrence (3Pn, 4RS) cod (*Gadus morhua*) and their impact on reproductive potential and projections of population growth

Mise à jour des paramètres du cycle vital de la morue (*Gadus morhua*) du nord du golfe du St-Laurent (3Pn, 4RS) et leur impact sur le potentiel reproducteur et les projections de croissance de la population

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ABSTRACT

Updated time series of life history characteristics of cod in the northern Gulf of St. Lawrence indicate that important changes occurred in the age structure of the stock with 7+ fish only representing 13 to 19% of 4+ fish in the stock since 2008 compared to 25 to 32% in the early 2000's. An apparent decrease in female age at 50% maturity is associated with this lower proportion of older fish. Decreasing trend in egg production per mature fish and low recruitment would also negatively affect the reproductive potential of the stock. Moreover, the higher natural mortality observed in the recent years has an important impact on the potential rate of population increase. While potential rate of population growth in the absence of fishing was estimated as ~ 15% per year in the early 2000's it is now only estimated as ~ 3.3% per year with a declining trend since 2008. Projections of stock dynamics over 36 years using a demographic model assuming that current age-specific survival and reproduction were to be maintained in the future indicate a very slow recovery of the spawning stock biomass (SSB) in the absence of fishing and an absence of rebuilding of the stock if the fishing mortality level observed in 2011 was maintained or increased. In all scenarios, these extrapolations of the consequences of the present population productivity level indicate that SSB trajectory would not allow the stock to attain in the short and medium term the limit reference level of 116,000 t of SSB established for this stock. These results are in agreement with the conclusions of the recovery potential assessment of the stock done in 2011.

RÉSUMÉ

La mise à jour des séries temporelles des différentes caractéristiques du cycle vital de la morue du nord du golfe du St-Laurent indiquent un important changement dans la structure d'âge du stock, les poissons âgés de plus de 7 ans ne représentant plus, depuis 2008, que 13 à 19 % des poissons adultes de plus de 4 ans comparativement à des pourcentages de 25 à 32 % au début des années 2000. Une diminution apparente de l'âge à 50 % de maturité chez les femelles serait associée à cette plus faible proportion de poissons âgés. La diminution de la production d'œufs par femelle mature et le faible recrutement affecteraient également de façon négative le potentiel reproducteur du stock. De plus, le taux plus élevé de mortalité naturelle observé au cours des années récentes a un impact important sur le taux potentiel d'accroissement de la population. Alors que le taux potentiel d'accroissement de la population en absence de pêche était estimé à environ 15 % par année au début des années 2000, il serait maintenant estimé à seulement 3,3 % par année avec une tendance négative depuis 2008. Des projections de la dynamique de ce stock sur une période de 36 ans à l'aide d'un modèle démographique assumant que les taux spécifiques actuels de survie et de reproduction à l'âge soient maintenus dans le futur indiquent un très lent rétablissement de la biomasse du stock reproducteur (BSR) en absence de pêche et une absence de rétablissement du stock avec le maintien ou l'augmentation du niveau de mortalité par la pêche observé en 2011. Dans tous les scénarios, les extrapolations des conséquences du niveau actuel de productivité de la population indiquent que la trajectoire de la BSR ne permettrait pas au stock d'atteindre à court ou moyen terme le niveau de référence limite de 116 000 t de BSR établi pour ce stock. Ces résultats sont en accord avec les conclusions de l'évaluation du potentiel de rétablissement de ce stock réalisée en 2011.

INTRODUCTION

Since the collapse and the first moratorium on the cod stock from the northern Gulf of St. Lawrence (nGSL) in 1994, few signs of recovery have been observed (DFO, 2009). The estimated number of spawners decreased from 200 million in 1983 to 7 million in 1994. Slight increase was observed afterwards with number of spawners reaching 20 million individuals in 2011. As in many of the northwest Atlantic cod stocks that collapsed in the 1992-1994 period, the lack of recovery was attributed to a lower productivity mainly associated with increased natural mortality, decreased body growth, reduced recruitment rates in some cases and to fishing mortality even though removals were limited (Sinclair, 2001; Chouinard et al., 2005; Shelton et al., 2006). In nGSL cod, many life history traits determining the reproductive potential of the stock reached minimum values in the early 1990s (Lambert, 2011). These low values coincided with a period when temperature conditions in the Gulf of St. Lawrence where below normal (Galbraith et al., 2011). These conditions combined with a high fishing intensity resulted in a rapid collapse of the stock. While environmental conditions significantly contributed to the collapse of the stock, fishing mortality appears to be the major limiting factor for the rebuilding of nGSL cod stock (Lambert, 2011).

In 2011, a recovery potential assessment of the stock was done using updated biological information and reference points (DFO, 2011; Duplisea and Fréchet, 2011). It was estimated that the spawning stock biomass (SSB) has been below the limit reference point (B_{lim}) of 116,000 t since 1990 (DFO, 2011). Projections of stock size assuming no fishing and future productivity conditions similar to those previously observed indicated that although increasing, population size would remain below B_{lim} after 36 years. Projections using fishing mortality levels for the 2007-2009 period (F=0.47; average over ages 7-9) indicated that over the long term, SSB would decline to 25% of the B_{lim} level. Projections using a demographic model based on the life history characteristics of the stock also indicated declines in spawning stock numbers (SSN) and SSB over 36 years under an average F of 0.47 with projected SSB well below B_{lim}. In the absence of fishing, no further decline in SSN and SSB was predicted but the recovery over 36 years was very slow.

The present work is an update of the time series of life history characteristics of cod in the nGSL from 1984 to 2011(Lambert, 2011). Annual estimates of stock egg production, age-specific survival and reproductive rate are derived from these time series and used in a demographic model (Leslie matrix) to update estimates of instantaneous rate of population growth (r). Mean age-specific survival and reproductive rate for the 2007-2011 period are used to project changes in population size under current fishing mortality and in the absence of fishing.

METHODS

Age, length, mass, sex, maturity, and fecundity data for cod in the nGSL that were collated and analyzed by Lambert (2011) were updated and used in the present study. A complete description of the surveys, collected data and methods used to build time series on length-at-age, sex ratio, proportion of mature females-at-age, and fecundity-at-age from these biological characteristics for the period between 1984 and 2009 is given in Lambert (2011).

Annual total egg production (TEP) is used as a measure of the reproductive potential of the stock. TEP defined as :

$$TEP = n_a \, s_a \, m_a \, e_a$$

incorporates on an annual basis the number of fish at age, n_a, the sex ratio at age, s_a, the proportion of females mature at age, m_a, and the number of eggs produced by a female of age a, e_a. Numbers-at-age are obtained from the sequential population analysis (SPA) of cod in the nGSL (DFO, 2012).

Life tables incorporating age-specific rates of survival and reproduction were used to estimate reproductive rate and instantaneous rate of population increase (Caswell, 2001). The intrinsic rate of population increase (r – malthusian parameter) used as a proxy of stock productivity was obtained by solving the Euler-Lotka equation :

$$\sum_{x=\alpha}^{w} e^{-rx} \, l_x \, m_x = 1$$

where l_x is the probability of survival to age x, m_x the number of female offspring produced at age x, α is the age at first maturity and w the maximum reproductive age. A maximum reproductive age of 20 years was used for the calculations.

Year-specific estimates of offspring production (assuming a 1:1 male:female ratio at birth) was estimated as:

$$m_x = 0.5 \, M_x \, Fec_x$$

with M_x representing the proportion of females that are mature at age x and Fec_x the potential fecundity of a female at age x.

The survival probability (l_x) was evaluated separately for the following groups: pre-recruits from birth to age 3 years and age 3+ fish.. Survival from birth to age 3 years was calculated with the time series of the annual total egg production (TEP) and the abundance of cod of age 3. Survival over the first 3 years of life was estimated as:

$$S_t = N_{3,t} / TEP_{t-3}$$

with $N_{3,t}$ representing total abundance of age 3 fish in year t, and TEP_{t-3} the annual total egg production in year t-3. Average annual total mortality (Z) in each of the 3 years was calculated as -ln S_t/3.

The probability of surviving to age x (l_x) for age 3+ fish was calculated using the results of the sequential population analysis (SPA). Values of instantaneous rate of natural mortality (M = 0.2–0.4) consistent with the assessment were used to determined survival probability of age 3+ cod in the nGSL (DFO, 2012). The M values for all ages were set at 0.2 prior to 1986 and 0.4 for the 1986–1996 period. They were estimated within the SPA for three periods: 1997 to 2001 (M= 0.186 ± 0.036), 2002 to 2006 (M = 0.308 ± 0.025) and 2007 to 2011 (M = 0.404 ± 0.039).

Population projection matrix derived from life tables of age-specific survival and reproduction was used to predict changes in population size over time under different fishing scenarios (Caswell, 2001). A stochastic projection model using Monte Carlo simulation was used for the calculations. Simulations were done using 1000 iterations of random values from a normal distribution for the mean age-specific survival and reproduction estimates. Mean values with standard errors were calculated for the 2007-2011 period. Spawning stock numbers from the SPA in 2011 were used as starting values for the projections. These projections should not be viewed as forecasts of future stock size. They are extrapolations of the consequences of the present population productivity level on the projected SSB trajectory.

Life tables analysis and population projections were made using PopTools, an add-in tool for PC versions of Microsoft Excel downloadable from: http://www.cse.csiro.au/poptools.

RESULTS AND DISCUSSION

LIFE HISTORY PARAMETERS

Updated time series of population numbers-, sex ratio-, mean lengths-, maturity-, and fecundity-at age (Annex 1 to 5) from Lambert (2011) indicate large temporal variations in growth and reproductive characteristics for nGSL cod (Figure 1). Mean length at age 3 and 6 used as proxies of juvenile and adult growth, respectively, were both at minimal levels from the end of the 1980's to mid 1990's. In the 2000's, mean lengths were ~ 15% and ~ 8% higher for age 3 and 6, respectively (Figure 1). However, a negative trend in mean length at age 3 is observed since 2006 while mean length at age 6 oscillates between the mean value and +1 SD with no trend. The proportion of older fish used as an index of the age structure of the stock indicated that early in the time series approximately 25% of the adult fish (i.e. 4+) were older than age 7. At the maximum in the early 2000's, older fish represented 32% of the adult population. Steep declines were observed at the beginning of the 1990's and the end of the series with 7+ fish representing only 15 to 20% of the adult fish since 2008 (Figure 1). The age at 50% maturity varied between 3.9 and 6.3 with highest ages at maturity between 1984 and 1994. Lowest values (< 4.3) were observed in 1995-1997 and from 1998 onward values were slightly higher but lower than the mean value for the time series. More variable age at 50% maturity was observed after 2007 with low values (i.e. < 4.3) for 2 of the last 3 years. The most important change in the potential fecundity of cod was observed during the period of 1990 to 1997. During that period the potential fecundity of a 50 cm cod (mean size of adult fish) was clearly below the mean for the entire time series. With the exception of two high values in 1998 and 2005, fecundity values were close to the mean of 500,000 eggs observed for the time series following 1998. Finally, mean sex ratio indicated that 51% of the population was represented by females with minimum and maximum proportion of 46% and 58%.

TOTAL EGG PRODUCTION AND RECRUITMENT

Annual total egg production (*TEP*) of cod in the northern Gulf of St. Lawrence followed the same declining trend as observed for the spawning stock biomass (SSB) between 1984 and 2011. However, on a relative basis, marked changes in the reproductive potential were observed between the years (Figure 2). Mean egg production per mature female decreased at the beginning of the 1990s to reach minimum values around the mid 1990s. An increase in this relative index of egg production was observed in the 2000s but a declining trend is observed since 2005. Recruitment in 2010 and 2011 is within the range of the observed relationship between stock egg production and recruitment (Figure 3). Number of recruits for those two years is low with the number of recruits in 2011 (7.7×10^6) being the lowest for the whole time series.

AGE SPECIFIC SURVIVAL AND REPRODUCTION

Estimates of juvenile and adult survival (l_x) and female offspring production at age (m_x) obtained from population numbers at age, *TEP*, growth, maturity and fecundity characteristics showed patterns of variation through time (Figure 4). Total juvenile mortality (mean *Z*/year for age 0 to 3) varying between 4.3 and 4.8 was higher before 1996 than in the rest of the series where it ranged excluding the much lower mortality rate observed in 1997 (Z=3.9) between 4.2 and 4.5.

The decreasing trend in Z since 2002 stopped in 2010. Natural mortality rates estimated from the sequential population analysis (DFO, 2012) indicated variations in M from 0.19 to 0.4 with highest values observed in the 1986-1996 and 2007-2011 periods. Increased variability in female offspring production at age (m_x) was observed in older fish. Globally, female offspring production which was high at the beginning of the series decreased to minimum values in the 1990-1994 period, increased afterwards until 2005 and is slightly decreasing since that time (Figure 4).

Annual estimates of instantaneous rate of population increase (r) expressed as potential rate of population growth in percent per year were negative for 10 consecutive years between 1986 and 1995 (Figure 5). These negative values were observed with age specific survival calculated with natural mortality and total mortality indicating that population size would have decreased even in the absence of fishing. Potential rate of population growth was higher in the 1997-2001 period. Since 2002, an important decrease is observed with many negative values when considering observed fishing mortality. Moreover in 2011, the estimate of potential rate of population growth in the absence of fishing was negative indicating a potentially important decrease in the productivity of the stock.

POPULATION PROJECTIONS

Observed age-specific survival and reproduction in the last 5 years (2007-2011) were used to calculate the recent population growth statistics and to realize projection of population size over time (Table 1) assuming that the mean life history characteristics of the stock observed in the last 5 years would remain stable. Population growth statistics under three scenarios were examined; absence of fishing, F level observed in 2011 (i.e. F=0.09) and a doubling of present F level (i.e. F = 0.2). Age-specific relative F (F at age / F (7-9)) estimated from the SPA output (DFO, 2012) was used to calculate total mortality at age used for the projections (Figure 6). Life table statistics indicate that the absence of fishing might result in a rate of increase in population numbers of 3.3% per year with a doubling time of 21.5 years (Table 2). Under current F, the rate of increase in population numbers would essentially be nil (i.e. 0.2% per year). With a F of 0.2, it is estimated that population size would decrease at a rate of 2.4% per year (Table 2). Estimates of generation time indicate that the mean age of reproductive females produced by the offspring of a cohort is between 7.1 and 8.4 years.

Projections of population size over time using the same scenarios of fishing level indicate a very slow recovery of the spawning stock biomass (SSB) of cod in the nGSL in the absence of fishing and an absence of rebuilding of the stock if the fishing mortality level observed in 2011 was to be maintained or increased (Figure 7). SSB projections in all cases would be well below estimated B_{lim} (116,000 t) after 36 years. Under current F, SSB would remain at ~ 17,000 t a level representing 15% of B_{lim}. With a F of 0.2, SSB would decrease to ~ 6,500 t after 36 years to a level only representing 5% of B_{lim}. Corresponding catches for a F level of 0.09 over 36 years would vary between 1,800 and 2,500 t while for a F of 0.2 with decreasing SSB catches would decrease from a maximum of 4,300 t to 1,600 t after 36 years (Figure 8). In the absence of fishing, SSB would reach a level of 51,000 t after 36 years a level representing 44% of B_{lim}.

While these projections should not be considered as forecasts of long term future stock size, it is nevertheless indicating that if the mean productivity level of the stock observed in the last 5 years was to be maintained the trajectory for SSB would not allow the stock to reach the limit reference point established for this one on a short or medium term even in the absence of fishing. Key life history traits and indices of population abundance could be used to set a growth trajectory necessary to reach a determined population level in a specific time period. A regular monitoring of the intrinsic rate of population increase derived from life history traits and indices

of population abundance could be used to adjust fishing effort to maintain the planned population growth trajectory during the recovery period.

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Table 1. Mean, standard deviation (SD) and coefficients of variation (CV) for juvenile total mortality (Z per year), adult natural mortality (M per year), and female offspring production at age (m_x) for cod in the nGSL between 2007 and 2011.

	Age	Mean	SD	CV (%)
Z / year	0 - 3	4.298	0.120	2.8
M / year	3 - 20	0.404	0.039	9.6
m_x	3	4,979	4,445	89.3
	4	32,709	29,688	90.8
	5	116,329	107,709	92.6
	6	242,897	230,040	94.7
	7	372,125	360,220	96.8
	8	500,339	489,707	97.9
	9	630,888	609,255	96.6
	10	763,771	720,853	94.4
	11	897,508	826,347	92.1
	12	1,030,373	925,213	89.8
	13	1,160,821	1,016,829	87.6
	14	1,287,605	1,100,841	85.5
	15	1,409,775	1,177,178	83.5
	16	1,526,650	1,245,997	81.6
	17	1,637,777	1,307,617	79.8
	18	1,742,893	1,362,467	78.2
	19	1,841,883	1,411,042	76.6
	20	1,934,752	1,453,863	75.1

Table 2. Life table statistics of cod in the nGSL for the period 2007 - 2011. Reproductive rate (R_0), instantaneous rate of increase (r), increase in population numbers in % per year (Rate / year), generation time (G), and doubling time in population numbers (DT) are calculated for age-specific natural mortality (M) and age-specific total mortality Z (M+F) for mean F (ages 7 to 9) of 0.09 and 0.2.

	$F = 0$	$F = 0.09$	$F = 0.2$
R_0	1.316	1.012	0.842
r	0.032	0.002	-0.024
Rate / year (%)	3.3	0.2	-2.4
GT	8.4	7.6	7.1
DT	21.5	453.6	-28.6

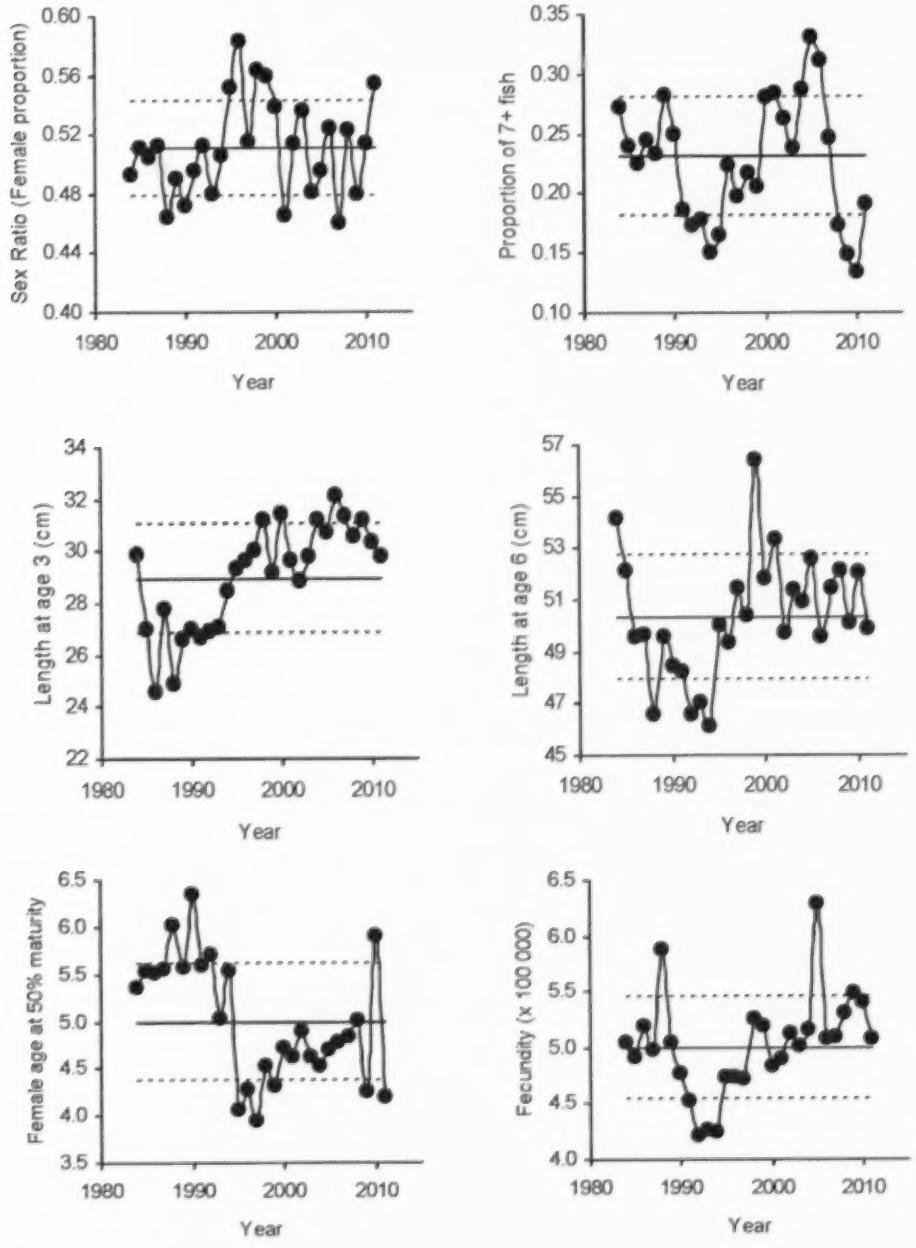


Figure 1. Interannual variations in the different biological factors determining total egg production of cod in the nGSL for the period between 1984 and 2011. Annual estimates for sex ratio, proportion of 7+ fish in the adult stock (i.e. index of age structure), lengths at age 3 and 6 (i.e. indices of juvenile and adult growth), female age at 50% maturity and fecundity of a standard 50 cm fish (fecundity at mean adult size) are presented along with mean values and standard deviations for the entire period.

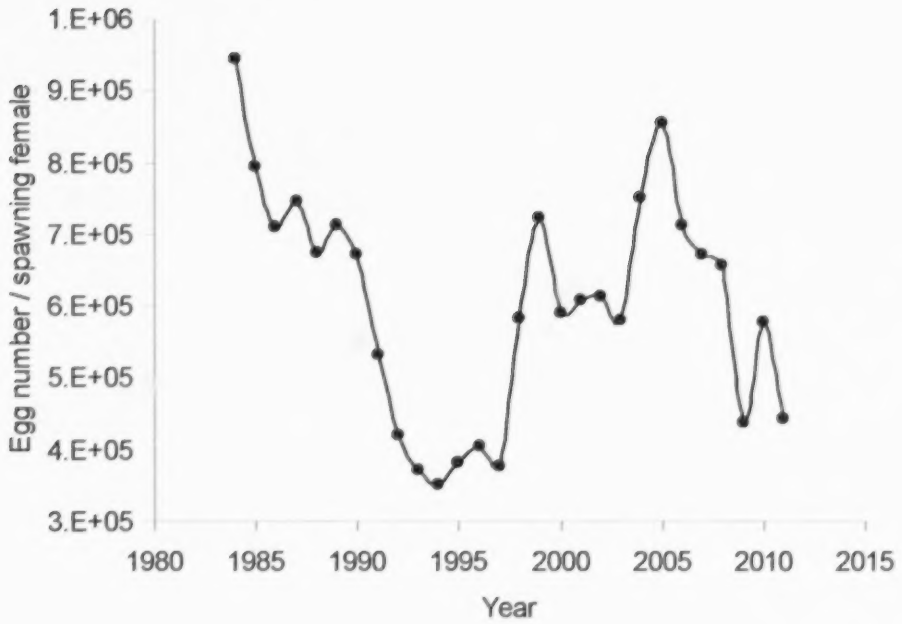


Figure 2. Mean egg production per mature female for cod in the nGSL between 1984 and 2011. Mean egg production was estimated from annual total egg production of the stock and the number of mature females obtained from the sequential population analysis.

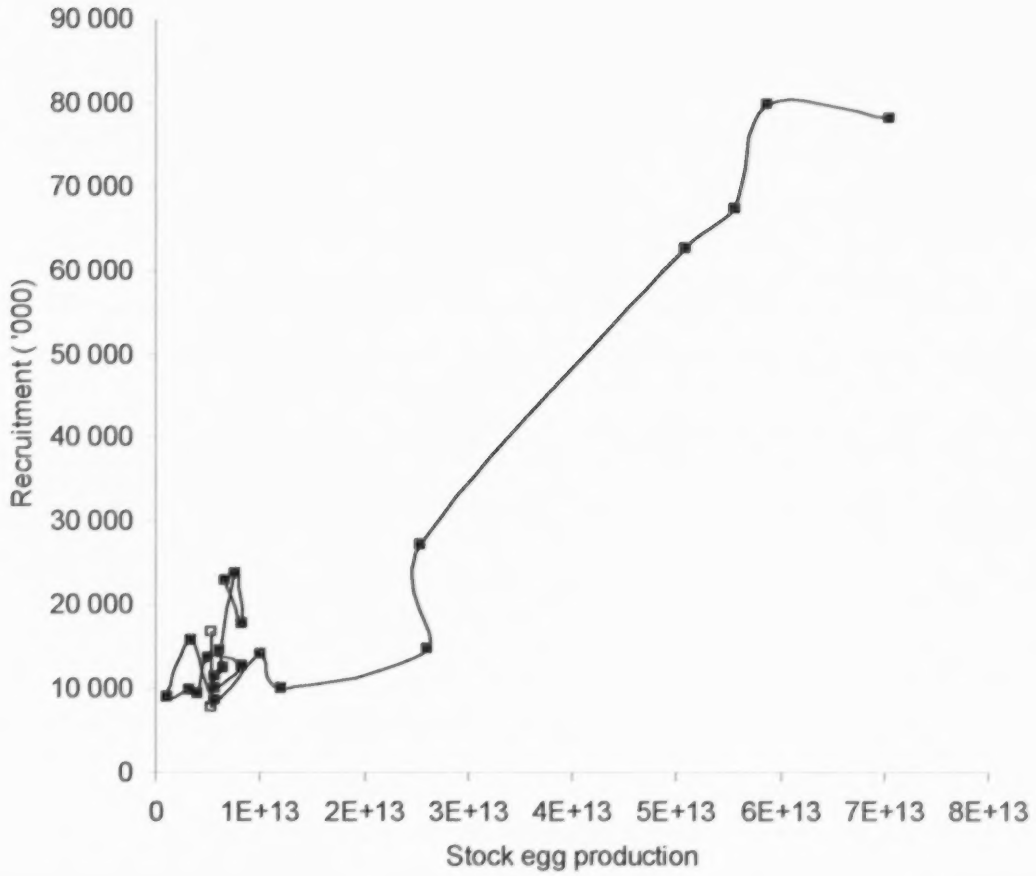


Figure 3. Stock-recruit relationship for nGSL cod between 1984 and 2011 estimated from annual total stock egg production in year t-3 and recruits of age 3 in year t. Open dots represent recruitment in 2010 and 2011.

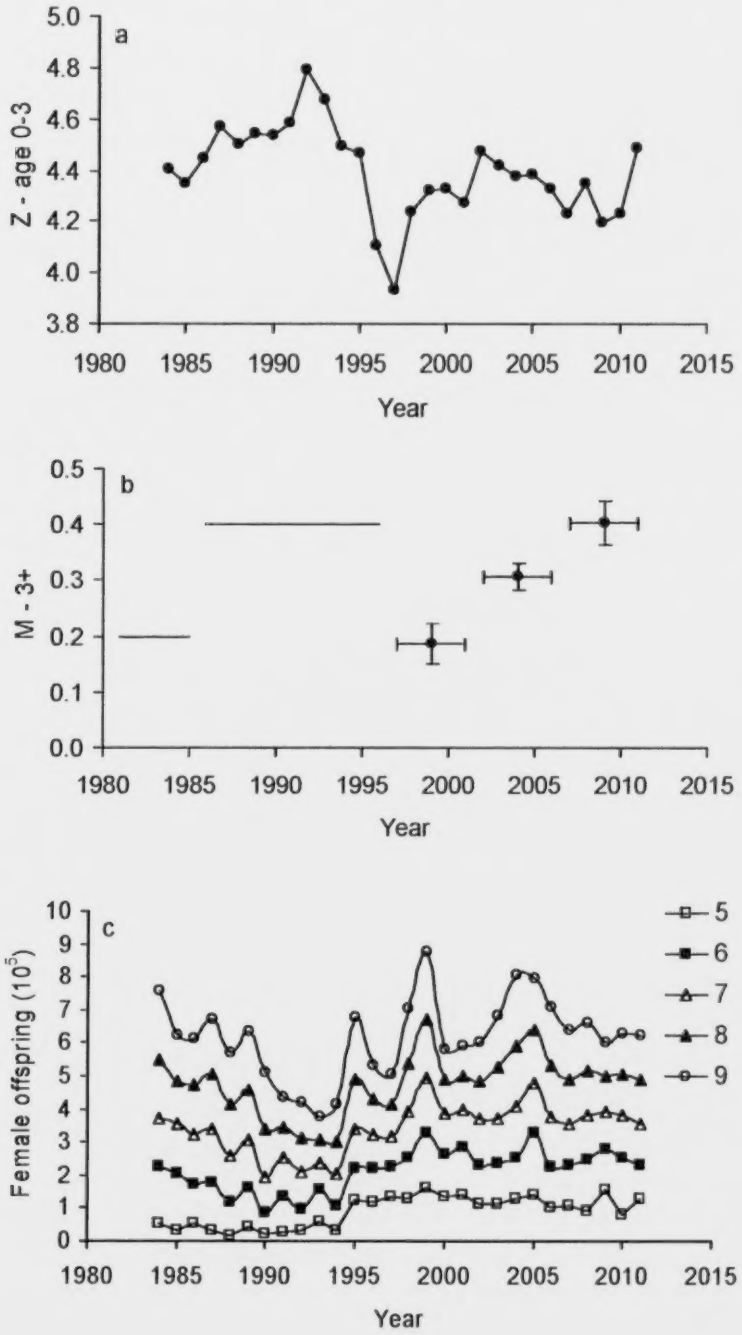


Figure 4. Annual estimates of juvenile total mortality (Z age 0-3), adult natural mortality (M age 3+), and female offspring production at age of nGSL cod for the period between 1984 and 2011. Juvenile mortality (a) was estimated from age 3 fish in year t and TEP in year t-3, adult natural mortality (b) is taken from the SPA model formulation of 2011 for this stock and female offspring production (c) from length, proportion of mature fish and fecundity at age for age 5 to 9. Thick lines for adult natural mortality represent fixed values and circles the values estimated by the SPA with SE (vertical line) over the block of years indicated by the horizontal line.

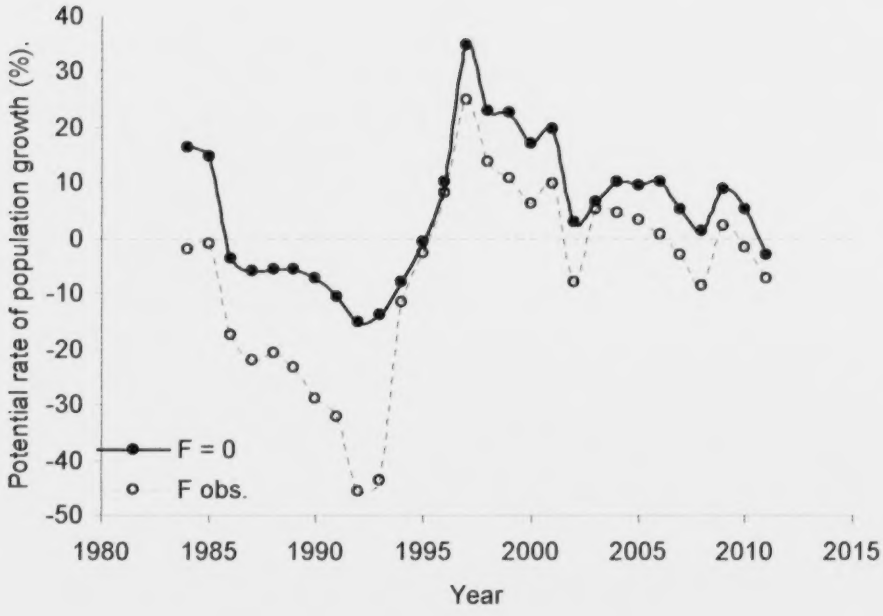


Figure 5. Annual estimates of the instantaneous rate of population increase of cod in the nGSL for the period between 1984 and 2011 using yearly estimates of age-specific survival and reproduction. Age-specific survival was estimated for both natural mortality M (F=0) (●) and total mortality (F obs.) (O) at age obtained from M and observed F at age.

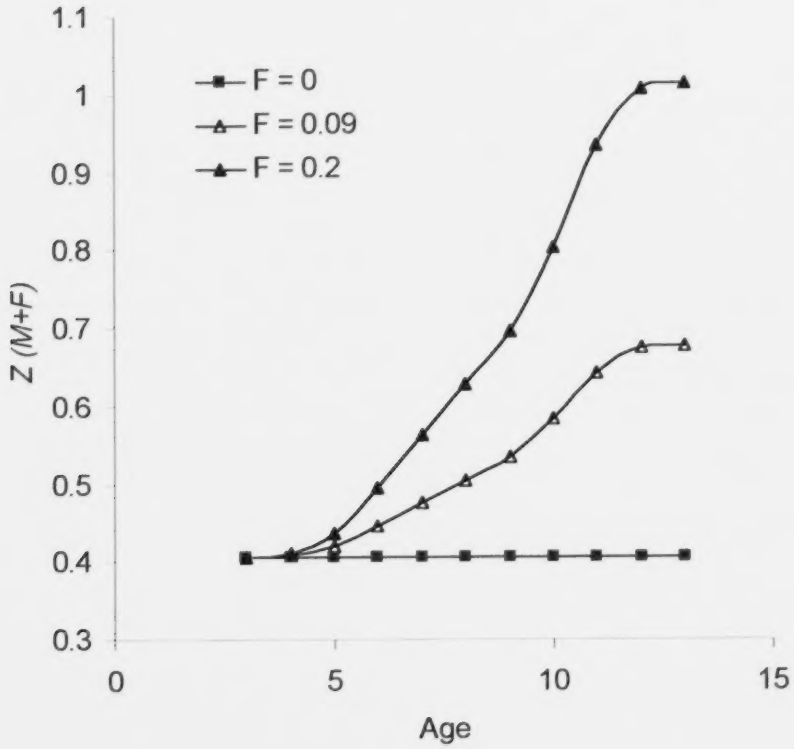
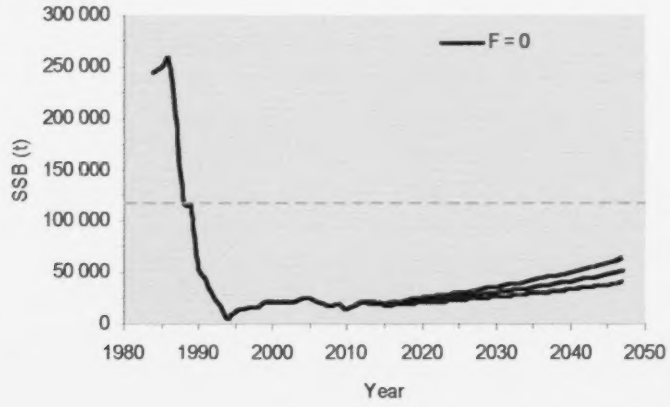
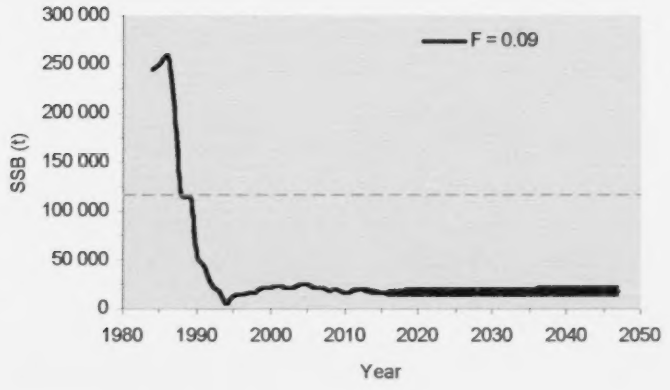


Figure 6. Age-specific total mortality Z=(M+F) for different levels of F estimated for ages 7 to 9. Age-specific relative F (F at age / F (7-9)) estimated from the SPA output in 2010 and 2011 were used to calculate total mortality (Z) at age.





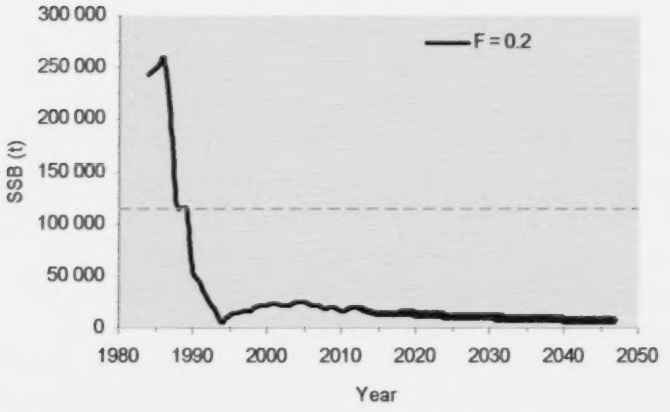


Figure 7. Expected change in SSB over time in the absence of fishing and with a mean F (ages 7 to 9) of 0.09 and 0.2. SSB is estimated from Leslie matrix projection of age-specific survival and reproduction using mortality and mean reproductive parameters for the 2007-2011 period. A stochastic projection using Monte Carlo simulation was used to determine mean SSB with 95% confidence intervals. The dashed lines represent the estimated limit reference level (B_{lim}) of 116,000 t of SSB established for the stock

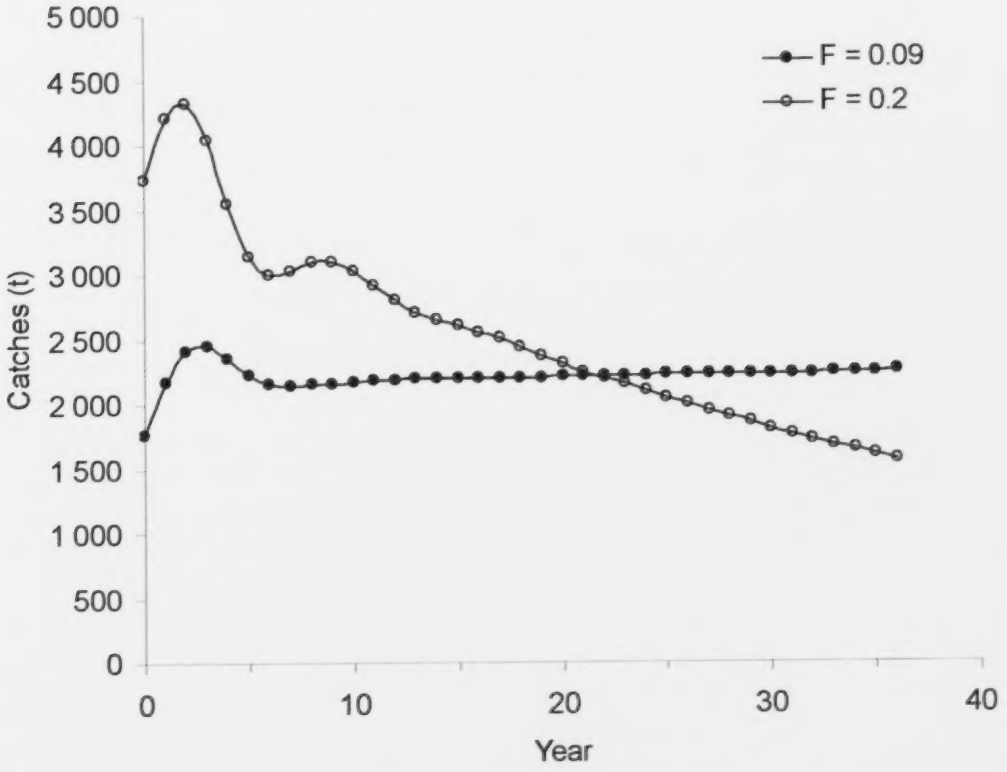


Figure 8. Catches (t) per year representing a fishing mortality of 0.09 and 0.2 for the projections of SSB in each year.

Annex 1. Population numbers for nGSL cod (3Pn, 4RS) estimated from the sequential population analysis (SPA).

Year/Age	3	4	5	6	7	8	9	10	11	12	13
1984	126 167	136 839	84 769	56 994	57 762	22 768	15 091	5 369	1 809	756	302
1985	165 601	103 255	109 373	62 430	34 535	29 149	12 010	7 262	2 520	748	257
1986	125 675	135 425	82 264	75 218	38 687	18 686	15 063	6 978	3 868	1 321	433
1987	78 223	84 067	88 815	48 233	37 825	16 441	7 704	5 173	2 850	1 206	517
1988	79 791	52 422	55 382	52 710	22 440	15 854	5 296	2 274	1 996	750	353
1989	67 302	53 391	34 105	32 236	26 111	10 163	6 510	2 335	998	681	282
1990	62 672	44 813	34 260	18 773	15 027	10 641	3 547	2 214	705	289	158
1991	27 162	41 716	27 539	16 786	7 847	5 734	3 955	1 059	757	255	105
1992	14 746	18 118	25 527	12 892	5 765	2 602	1 791	1 075	324	168	80
1993	9 942	9 634	8 705	9 806	3 827	1 191	451	318	191	54	31
1994	14 063	6 527	4 887	2 812	1 896	371	118	40	47	27	18
1995	8 607	9 426	4 374	3 243	1 832	1 199	211	73	21	30	17
1996	15 841	5 768	6 310	2 913	2 131	1 196	777	127	45	12	19
1997	8 951	10 617	3 848	4 181	1 866	1 356	755	487	75	29	8
1998	9 749	7 467	8 590	2 857	2 788	1 122	661	429	182	34	15
1999	9 355	8 146	6 205	6 841	2 062	1 902	732	427	246	115	13
2000	9 382	7 811	6 757	4 990	4 829	1 304	881	271	195	82	47
2001	13 711	7 824	6 469	5 266	3 542	2 867	745	346	83	117	56
2002	12 590	11 422	6 369	5 115	3 804	2 364	1 466	319	119	24	70
2003	10 093	9 280	8 362	4 450	3 024	2 165	1 046	527	94	49	12
2004	11 517	7 438	6 829	6 140	3 232	2 174	1 557	757	374	60	35
2005	12 575	8 486	5 474	4 944	4 286	2 049	1 316	947	472	218	38
2006	14 425	9 265	6 239	3 960	3 419	2 608	1 140	700	573	226	114
2007	23 670	10 626	6 795	4 405	2 456	2 059	1 223	560	385	322	116
2008	17 851	15 899	7 067	4 357	2 588	1 326	867	416	194	157	183
2009	22 948	11 985	10 572	4 548	2 481	1 244	549	200	122	48	73
2010	16 714	15 395	7 946	6 594	2 526	1 251	580	179	61	42	17
2011	7 747	11 212	10 226	5 105	3 977	1 359	605	230	61	19	11

Annex 2. Sex ratio-at-age expressed as the proportion of females for nGSL cod (3Pn, 4RS)

Year/Age	3	4	5	6	7	8	9	10	11	12	13
1984	0.46	0.52	0.46	0.49	0.49	0.45	0.56	0.34	0.43	0.91	0.49
1985	0.52	0.53	0.50	0.52	0.50	0.46	0.57	0.36	0.43	0.92	0.41
1986	0.46	0.54	0.47	0.50	0.47	0.44	0.58	0.31	0.45	0.91	0.45
1987	0.45	0.53	0.48	0.53	0.49	0.51	0.64	0.39	0.57	0.85	0.65
1988	0.43	0.50	0.43	0.45	0.48	0.46	0.59	0.35	0.44	0.83	0.53
1989	0.46	0.51	0.48	0.43	0.58	0.42	0.52	0.43	0.52	0.38	0.44
1990	0.52	0.49	0.49	0.42	0.43	0.53	0.41	0.54	0.24	0.44	0.75
1991	0.47	0.47	0.55	0.44	0.49	0.53	0.54	0.47	0.69	0.68	0.21
1992	0.50	0.52	0.51	0.53	0.49	0.41	0.42	0.54	0.50	0.48	0.35
1993	0.56	0.48	0.49	0.48	0.51	0.32	0.21	0.56	0.62	0.47	0.69
1994	0.47	0.48	0.52	0.52	0.54	0.64	0.48	0.51	0.44	0.74	0.41
1995	0.60	0.57	0.51	0.64	0.42	0.56	0.25	0.37	0.50	0.50	0.50
1996	0.52	0.55	0.60	0.65	0.61	0.52	0.46	0.50	0.50	0.50	0.50
1997	0.49	0.50	0.55	0.62	0.46	0.41	0.44	0.36	0.50	0.50	0.50
1998	0.54	0.62	0.51	0.64	0.51	0.73	0.54	0.21	0.50	0.50	0.50
1999	0.47	0.53	0.63	0.54	0.61	0.50	0.49	0.69	0.49	0.50	0.50
2000	0.58	0.62	0.65	0.46	0.37	0.56	0.33	0.46	0.73	0.55	0.50
2001	0.56	0.51	0.47	0.43	0.47	0.43	0.40	0.17	0.58	0.50	0.50
2002	0.65	0.49	0.58	0.58	0.36	0.35	0.86	0.73	0.50	0.50	0.50
2003	0.50	0.53	0.51	0.58	0.57	0.62	0.49	0.15	0.75	0.50	0.50
2004	0.46	0.46	0.49	0.50	0.47	0.49	0.55	0.41	0.47	0.26	0.58
2005	0.51	0.52	0.55	0.50	0.39	0.52	0.40	0.49	0.50	0.48	0.57
2006	0.49	0.57	0.47	0.55	0.49	0.66	0.49	0.31	0.27	0.27	0.27
2007	0.50	0.47	0.40	0.52	0.38	0.57	0.56	0.35	0.39	0.39	0.39
2008	0.40	0.52	0.54	0.54	0.51	0.42	0.53	0.50	0.62	0.62	0.62
2009	0.48	0.52	0.45	0.53	0.44	0.36	0.26	0.44	0.44	0.44	0.44
2010	0.53	0.43	0.64	0.54	0.67	0.31	0.53	0.53	0.53	0.53	0.53
2011	0.50	0.54	0.57	0.52	0.59	0.64	0.44	0.44	0.44	0.44	0.44

Annex 3. Mean length-at-age in early spring for nGSL cod (3Pn, 4RS).

Year/Age	3	4	5	6	7	8	9	10	11	12	13
1984	29.8	38.0	46.3	54.1	56.9	60.2	63.2	67.2	75.7	86.0	79.9
1985	27.0	38.0	45.0	52.1	57.5	59.1	62.7	63.4	72.4	75.3	79.4
1986	24.5	36.2	44.7	49.5	54.2	58.4	61.9	66.2	66.8	73.2	80.6
1987	27.8	36.5	42.4	49.6	54.6	59.8	68.3	69.2	71.2	77.2	71.8
1988	24.9	30.5	38.1	46.6	51.5	57.1	61.3	64.1	69.0	73.1	69.5
1989	26.6	34.5	43.4	49.6	54.8	57.6	61.9	68.9	72.3	78.0	74.4
1990	27.0	36.2	43.1	48.5	51.9	55.6	60.6	63.6	70.2	76.9	88.6
1991	26.7	36.1	42.4	48.3	53.2	55.0	57.2	64.0	65.2	103.2	66.6
1992	26.9	36.5	42.6	46.6	52.3	55.0	59.2	63.0	68.5	69.4	74.5
1993	27.1	34.9	42.3	47.0	51.6	55.1	60.2	57.4	64.9	63.4	71.1
1994	28.5	35.0	40.3	46.2	50.7	53.5	62.3	61.7	64.0	74.8	74.1
1995	29.3	37.1	43.5	50.0	55.3	59.3	65.9	73.3	69.8	86.4	87.2
1996	29.7	36.2	43.7	49.4	55.9	59.5	63.6	69.3	68.3	69.8	73.7
1997	30.0	38.3	46.0	51.5	55.5	59.6	61.9	66.1	69.8	72.0	73.8
1998	31.2	38.6	45.4	50.4	57.0	60.8	62.3	67.5	75.7	77.2	79.9
1999	29.2	40.4	46.0	56.4	64.3	64.8	70.8	63.2	69.3	91.7	83.6
2000	31.4	39.5	46.8	51.8	59.4	64.8	65.1	65.7	75.3	68.8	81.5
2001	29.6	38.2	46.1	53.3	57.9	63.1	68.4	67.5	69.2	66.1	99.1
2002	28.9	36.9	44.8	49.7	57.4	59.4	67.3	72.7	69.1	67.0	63.0
2003	29.8	37.9	44.9	51.4	56.4	64.1	61.9	72.4	81.0	77.3	71.5
2004	31.2	38.1	45.9	50.9	56.9	62.7	66.5	73.1	81.8	82.6	80.2
2005	30.7	37.7	44.1	52.6	57.0	62.1	62.6	67.3	70.1	74.3	63.0
2006	32.1	38.6	45.1	49.6	56.1	59.7	62.6	74.1	72.4	76.1	74.4
2007	31.3	38.4	46.2	51.4	56.0	58.3	63.7	65.2	72.9	75.4	75.0
2008	30.6	37.6	44.4	52.2	57.4	60.9	67.8	68.5	78.6	79.3	80.1
2009	31.2	37.9	44.2	50.1	57.9	63.7	63.3	63.3	68.1	70.8	89.0
2010	30.3	38.9	44.0	52.0	56.2	61.9	66.9	67.0	71.0	74.4	76.8
2011	29.8	37.0	44.7	49.9	56.5	61.7	67.7	70.1	78.0	72.3	101.0

Annex 4. Proportion of female mature-at-age for nGSL cod (3Pn, 4RS)

Year/Age	3	4	5	6	7	8	9	10	11	12	13
1984	0.00	0.02	0.34	0.91	0.97	0.99	1.00	1.00	1.00	1.00	1.00
1985	0.00	0.02	0.22	0.80	0.97	0.98	0.99	1.00	1.00	1.00	1.00
1986	0.00	0.06	0.38	0.70	0.90	0.96	0.99	1.00	1.00	1.00	1.00
1987	0.00	0.05	0.24	0.74	0.93	0.98	1.00	1.00	1.00	1.00	1.00
1988	0.00	0.02	0.13	0.58	0.83	0.95	0.98	0.99	1.00	1.00	1.00
1989	0.00	0.04	0.31	0.72	0.92	0.96	0.99	1.00	1.00	1.00	1.00
1990	0.00	0.04	0.18	0.47	0.69	0.85	0.96	0.98	1.00	1.00	1.00
1991	0.00	0.03	0.25	0.73	0.94	0.97	0.99	1.00	1.00	1.00	1.00
1992	0.01	0.10	0.34	0.59	0.86	0.93	0.97	0.99	1.00	1.00	1.00
1993	0.00	0.04	0.54	0.91	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1994	0.02	0.10	0.32	0.70	0.89	0.95	0.99	0.99	1.00	1.00	1.00
1995	0.07	0.49	0.88	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1996	0.13	0.39	0.77	0.92	0.98	0.99	1.00	1.00	1.00	1.00	1.00
1997	0.24	0.56	0.82	0.92	0.96	0.98	0.98	0.99	1.00	1.00	1.00
1998	0.04	0.26	0.75	0.93	0.99	1.00	1.00	1.00	1.00	1.00	1.00
1999	0.03	0.41	0.77	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2000	0.02	0.20	0.67	0.89	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2001	0.03	0.23	0.70	0.94	0.98	1.00	1.00	1.00	1.00	1.00	1.00
2002	0.04	0.20	0.60	0.83	0.96	0.98	1.00	1.00	1.00	1.00	0.99
2003	0.07	0.30	0.66	0.89	0.96	0.99	0.99	1.00	1.00	1.00	1.00
2004	0.05	0.27	0.75	0.92	0.98	1.00	1.00	1.00	1.00	1.00	1.00
2005	0.03	0.20	0.63	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2006	0.04	0.21	0.64	0.87	0.98	0.99	1.00	1.00	1.00	1.00	1.00
2007	0.03	0.17	0.64	0.89	0.97	0.98	1.00	1.00	1.00	1.00	1.00
2008	0.02	0.14	0.49	0.88	0.97	0.99	1.00	1.00	1.00	1.00	1.00
2009	0.10	0.40	0.78	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00
2010	0.02	0.15	0.41	0.86	0.95	0.99	1.00	1.00	1.00	1.00	0.00
2011	0.22	0.45	0.72	0.85	0.94	0.97	0.99	0.99	1.00	1.00	1.00

Annex 5. Fecundity-at-age for nGSL cod (3Pn, 4RS).

Year/Age	3	4	5	6	7	8	9	10	11	12	13
1984	75460	183798	380015	672887	816196	1007172	1211390	1523059	2359982	3774728	2908226
1985	50724	178194	330770	572589	825998	916959	1146360	1197750	1952402	2260201	2753881
1986	36112	153248	336631	500391	706076	937478	1176299	1511909	1583913	2219440	3166448
1987	56636	154688	270691	484790	691921	968318	1587593	1671294	1866041	2523108	1946955
1988	49873	102458	225012	460142	650643	932626	1192359	1385800	1789840	2180213	1800002
1989	49267	128698	297519	488596	707356	857077	1122272	1665278	1992125	2643044	2234463
1990	47294	140701	269949	421495	551432	719096	995934	1203536	1738214	2454182	4152475
1991	42190	130747	239477	392855	572566	656643	765044	1164232	1259694	6716169	1379824
1992	40195	126042	226868	321714	500344	613510	815358	1035803	1424024	1510206	1970086
1993	42942	110784	226477	337990	478688	615156	853056	723122	1136899	1053054	1598440
1994	53290	113862	191471	315965	448693	547054	958815	927495	1068177	1886443	1827820
1995	68094	159468	285686	474735	684626	883919	1294182	1904546	1596091	3460761	3586541
1996	74052	150615	293407	451748	704541	873545	1102834	1492869	1414794	1519007	1842564
1997	82077	190998	359078	523119	667853	848127	952397	1179635	1420413	1563527	1692216
1998	92733	201591	368296	541345	852393	1084747	1196960	1609999	2447320	2651728	3012685
1999	71260	235557	382394	806486	1313469	1362753	1887859	1260740	1774420	4916841	3531685
2000	99473	218018	388082	539394	862292	1151269	1142578	1159484	1878687	1334027	2440118
2001	76649	188462	366654	614996	821150	1110695	1470187	1396962	1519802	1282847	5554472
2002	74185	175673	347391	500589	829276	926904	1442937	1887138	1555458	1380490	1097299
2003	81484	190538	345381	551508	757246	1187868	1031149	1791099	2654907	2211844	1644415
2004	92344	192044	378705	550010	825453	1175844	1457473	2055500	3087214	3212113	2884766
2005	106515	223916	398854	753755	1011236	1387674	1428755	1862403	2152569	2664273	1466513
2006	93243	188141	340067	493876	792516	1019306	1233084	2319147	2174221	2641671	2472240
2007	89913	190941	378217	564643	779493	906707	1266375	1386486	2090365	2379598	2347828
2008	102689	206940	360253	615273	829718	986586	1396497	1390947	2206406	2196609	2205594
2009	105174	208104	356957	550261	913569	1277938	1233471	1217006	1571805	1793177	4082598
2010	98709	233745	350472	619694	791278	1093015	1408054	1375867	1662150	1928383	2130827
2011	86617	182781	348236	499558	759694	1013281	1385243	1531767	2202153	1638085	5403246